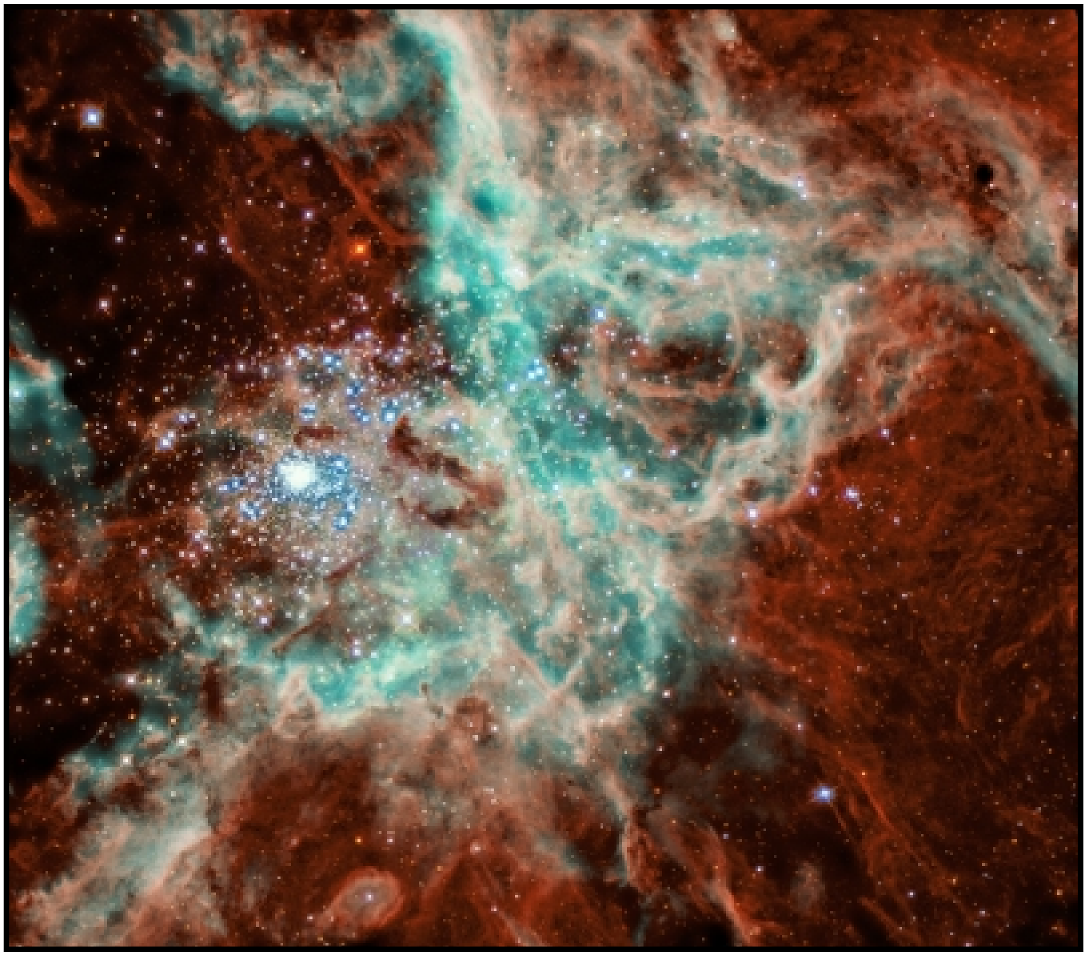

The 30 Doradus Nebula.
Credit: NASA, N. Walborn and J. Ma'iz-Apell'aniz (Space Telescope Science Institute), R. Barb'a (La Plata Observatory, La Plata, Argentina)

Astrophysics Branch (SSA) Overview

Scientists in the Astrophysics Branch pursue a wide range of laboratory and observational astronomy research. The Branch is particularly interested in studying the physical and chemical properties of astronomical phenomena by observing their radiation at infrared (and ultraviolet) wavelengths, beyond the range of visible light.

Planets, stars, and the interstellar medium of the Milky Way and other galaxies are rich in infrared spectral features which provide clues to their origins, physics, chemistry, and evolution. SSA researchers use state-of-the-art laboratories, ground-based, airborne, and space-based observatories to conduct their research. Astrophysics Branch scientists, engineers, and technicians also play key roles in developing new NASA space and airborne missions and instruments such as SIRTF, NGST, and SOFIA. The primary products of the Astrophysics Branch are new observations and interpretations of the universe and new instrumentation developed to make these observations.

Jesse Bregman
Chief, Astrophysics Branch (SSA)

ORGANIC SOLIDS COLOR THE ICY BODIES IN THE OUTER SOLAR SYSTEM

Dale P. Cruikshank and Bishun N. Khare

Many of the objects in the outer parts of the Solar System (at Jupiter and beyond) have surfaces (and interiors) composed largely of ordinary water ice, which can be readily identified by remote sensing observations. These bodies include the large satellites of the giant planets, Jupiter through Neptune, the rings of Saturn, the comets, Pluto-Charon, and the objects that populate the Kuiper disk and the Oort cloud. None of these bodies can be sampled directly at the present time, and we rely upon remote sensing to learn about their compositions and history of formation. The techniques of near-infrared spectroscopy, accomplished with large telescopes or by planetary probes, reveal the presence of water ice by showing characteristic absorption bands in the spectral region 1-5 micrometers.

While pure water ice is highly reflective of the sunlight incident on Solar System bodies, and is neutral in color, all of the ice-rich objects have distinct color, and many are nearly black. The coloration of the ice in the short wavelength region, 0.2-1.0 micrometers, has been especially difficult to model quantitatively, because minerals, a logical and naturally occurring contaminating material, do not have the appropriate optical properties.

We have succeeded in modeling the observed color in icy planetary satellites using mixtures of ice and complex organic materials. The organic material is synthesized in the laboratory in experiments that approximate the conditions of formation of similar material in various environments in space, usually by irradiating a mixture of simple gases (methane and nitrogen) or ices (water plus methanol, carbon dioxide, etc.) with ultraviolet light and charged particles from a plasma. The resulting brown-colored substance is termed “tholin”, and is structurally similar to some of the carbon-rich material found in carbonaceous meteorites. It is also similar in its optical properties to the organic-rich aerosol haze in the atmosphere of Saturn’s satellite Titan.

Specifically, we have successfully modeled the spectra of Saturn’s icy satellites Rhea and Iapetus, as well as Uranus’ satellite Titania and the moon of Neptune called Triton, by incorporating small amounts (<1 %) of various organic solid materials in the surface ices. All of these objects are key to understanding the origin of their respective satellite systems, the nature and timescale of geological activity on them, and the space environments in which they have evolved. The occurrence of complex organic materials in the surface ices of these bodies, spread throughout the planetary system, tells us that the products of prebiotic organic chemical processes occur in diverse environments far beyond Earth, and have existed from the beginnings of the Solar System to the present. ❑

FIGURE 2: Tholin, this orange-brown material produced by exposing a mixture of nitrogen and methane gases to ultraviolet light and charged particles from a plasma discharge, has optical properties similar to those of Saturn's satellite, Rhea. Modeling studies of the spectra of Rhea and other icy bodies in the outer Solar System suggest that tiny quantities of complex organic material of this kind occur as a contaminant on their surfaces. That organic matter may arise from meteoric infall of interplanetary dust, or it may be produced **in situ** *in the ice, by the influence of energetic particles in the space environment.*

A CRYOGENIC MULTIPLEXER FOR FAR-INFRARED ASTRONOMY

Jessie Dotson, Edwin Erickson, and Christopher Mason

The instruments for a new generation of large far-infrared telescopes, such as SOFIA, the Stratospheric Observatory for Infrared Astronomy, will require detector arrays with small enough pixels (picture elements) to exploit the improved angular resolution and a sufficient number of pixels to take advantage of the large fields of view. In order to make the step to arrays with more pixels, it is essential to develop suitable multiplexing amplifiers, or multiplexers. With this need in mind, we collaborated with personnel from University of Arizona and Raytheon Infrared Center for Excellence to develop the SBRC 190, a cryogenic multiplexer for far-infrared (FIR) photoconductor detectors operating at moderate backgrounds.

The circuit is based on the 32-channel CRC 696 CMOS device used on SIRTF, the cryogenic Space Infrared Telescope Facility. For applications such as those encountered on SOFIA or Herschel (the far infrared and submillimeter space observatory), the new device permits higher backgrounds, a wider range of backgrounds, faster sampling, and synchronization of sampling with chopping. Major design differences relative to the CRC 696 which have been incorporated in the SBRC 190 are: (a) an AC coupled, capacitive feedback transimpedence unit cell, to minimize input offset effects, thereby enabling low detector biases, (b) selectable feedback capacitors to enable operation over a wide range of backgrounds, and (c) clamp and sample & hold output circuits to improve sampling efficiency, which is a concern at the high readout rates required.

We have developed an end to end system suitable for testing the multiplexers in conditions similar to their eventual applications. This includes a photoconductor detector array, test dewar, driving electronics and the required software. The photoconductor array is composed of 2 rows of 24 Ge:Sb detectors mounted in integrating cavities. Incoming radiation is coupled to the cavities by light collecting cones. The liquid helium test dewar has room for the necessary optics and can achieve a range of operating temperatures from 2.0K to 4.2K. The driving electronics provides the bias voltages and clock signals required to drive the multiplexers. The electronics also contain 16 analog to digital converters to process the signals coming out of the multiplexers. We have developed software to control the driving electronics, receive the results and write them into a FITS (flexible image transport system) file. We have also developed software to analyze the obtained data.

Testing is currently underway. Initial results imply that the multiplexers are suitable for use in far-infrared instruments, but additional tests are necessary to fully examine their operation at faster rates and with novel read out strategies. ❑

SCIENTIFIC REQUIREMENTS OF THE NGST MID-IR INSTRUMENT

Thomas Greene

The Next Generation Space Telescope (NGST) will be the successor of the Hubble Space Telescope and is scheduled for launch in the year 2008. NGST will make unprecedented discoveries in the realms of galaxy formation, cosmology, stellar populations, star formation, and planetary systems. NGST is currently in the conceptual design phase of development, and Ames has been involved in defining and the scientific instrumentation it will need to conduct its observations. NGST will have 3 instruments: a near-IR camera (NIRCAM), and near-IR spectrometer (NIRSPEC), and a mid-IR instrument (MIRI).

MIRI will be the only NGST instrument built in a joint NASA – ESA (European Space Agency) collaboration. It must function as both a wide-field camera and a moderately-high resolution spectrograph over the wavelength range 5 – 28 microns (about 10 – 40 times longer than visible to the human eye). Ames personnel have contributed to planning its scientific observations, developing its infrared detectors, and determining its scientific requirements.

The Mid-IR Steering Committee (MISC) was constituted in the year 2001 to determine MIRI's detailed scientific requirements and oversee its conceptual design. This was an international scientific committee which included Ames representation. The MISC evaluated the MIRI scientific objectives and studied the instrument concept presented by the consortium of ESA states which will participate in MIRI development (the UK, France, Germany, Italy, and the Netherlands). The scientific objectives were translated into requirements for the instrument which were consistent with the MIRI instrument concept.

MIRI will consist of three optical subsystems, all employing reflective optics. A common set of fore optics will relay images from the NGST telescope focal plane to the MIRI camera and spectrograph subsystems. The fore optics will also provide a common focus mechanism, while the camera and spectrograph subsystems each have their own dedicated mirrors, field masks, filters, and detectors. The camera module images a field of 1.7 arc-minutes by 1.7 arc-minutes onto a 1024 x 1024 pixel detector. It includes a selection of filters and a coronagraphic mask which will allow suppressing the light of bright objects so that fainter ones close to them may be seen. This device will be used for searching for planets around nearby stars.

The spectrograph channel will take the light from every point in a small field (4 arc-seconds by 4 arc-seconds) and disperse it into a spectrum. The first element is an integral field unit which relays and realigns the small field into an image onto slits which are followed by optics and diffraction gratings which disperse the light. A multi-element camera then images the resultant spectra onto a dedicated infrared detector that is at least 1024 x 1024 pixels in size (preferably larger).

The MIRI subsystems will be built by ESA contractors and will be delivered to NASA once they are integrated and tested. The Jet Propulsion Laboratory will integrate this assembly with US infrared detectors and will test the entire instrument before delivering it to Goddard Space Flight Center for integration with the other NGST instruments. A new international mid-IR Science Team will provide scientific oversight for these activities. ❑

AN INTERSTELLAR ROSETTA STONE: A DATABASE OF THE INFRARED SPECTRA OF POLYCYCLIC AROMATIC HYDROCARBONS (PAHS)

Douglas M. Hudgins and Louis J. Allamandola

In recent years, a host of observations at infrared wavelengths has revealed the unmistakable fingerprint of polycyclic aromatic hydrocarbons (PAHs) in the spectra of objects at all stages of the lifecycle of matter in the interstellar medium (ISM). Moreover, analyses of meteorites and interplanetary dust particles have demonstrated that PAHs are also commonplace within our own solar system. Enormous molecules by interstellar standards, PAHs are composed of varying arrays of fused hexagonal rings of carbon atoms. Not only do these species hold tremendous potential as probes of the ISM, they also represent the single largest reservoir of prebiotic organic carbon in developing planetary systems.

Unfortunately, only rarely do scientists have the luxury of directly analyzing samples of extraterrestrial materials. Instead, they must rely heavily on spectroscopic data from remote sensing platforms such as NASA's Infrared Telescope Facility (IRTF), and the upcoming SOFIA (Stratospheric Observatory For Infrared Astronomy) and SIRTF (Space InfraRed Telescope Facility) missions for clues to the nature of these materials. The complete interpretation of these data, in turn, requires a thorough knowledge of the spectroscopic properties of PAHs — information obtainable only through appropriate laboratory studies. Toward this end, researchers in the Astrochemistry Laboratory at NASA Ames Research Center have been actively engaged in a systematic study of the infrared spectroscopic properties of PAHs under conditions that mimic those of interstellar space. The long-range goal of this work has been to compile a comprehensive infrared spectral database and to apply that data to model the observed interstellar spectra.

The diverse physical and chemical conditions in different astronomical objects give rise to variations in the native PAH population. These variations are reflected by (often subtle) differences in the observed infrared spectrum of the objects. By carefully modeling interstellar spectra using the spectra of a wide variety of PAHs representing a broad cross-section of sizes, structures and stabilities, scientists can determine which PAH structures are favored in a particular region. The power of this process is illustrated in Figure 3 below, which shows a comparison of the infrared spectrum of a star-forming region to a model spectrum generated by co-adding the spectra of species drawn from the database. In such a region, the interstellar material is bathed in the harsh, ionizing radiation of the adjacent hot young O- and B-type stars. The composition of the mixture that provides the best fit to the Orion spectrum is quite revealing about the nature of the PAH population there. 63% of the PAHs in the model mixture have highly stable, "condensed" structures — that is, the most compact arrangement of the hexagonal rings. Also, 70% of the model mixture is contributed by PAHs in their ionized forms. The PAH population reflected in the model spectrum is entirely consistent with what one would expect given the nature of this object. The molecules found in this region are those which have survived the fierce radiation from the nearby hot stars. Lesser stable components of the population have long since been 'weeded out', and a substantial fraction of the population has been ionized by the harsh ultraviolet radiation from the nearby cluster of hot stars. Thus, it is entirely reasonable that the model PAH mixture reflects a disproportionately large contribution from the hardiest species and from ionized species.

To date we have measured the infrared spectra of more than 100 neutral, cationic and anionic PAH species ranging in size from $C_{10}H_8$ to $C_{48}H_{20}$, and much of the wide acceptance and utility that the PAH model enjoys today rests upon these data. Amongst the species currently represented in the dataset are: (1) the thermodynamically most stable PAHs through coronene, $C_{24}H_{12}$; (2) species from the fluoranthene family, aromatic hydrocarbons which incorporate a five-membered ring in their carbon skeleton; (3) a variety of large PAHs ("LPAHs") having between 36 and 50 carbon atoms; and (4) a variety of "aza-PAHs", polycyclic aromatic compounds with a nitrogen atom incorporated into their carbon skeleton. This is the most extensive compilation of astrophysically relevant spectral data on PAHs available. Most of these spectra are available in the peer-reviewed chemical literature, and we are preparing an extensive review of this work's astrophysical implications for publication in the astronomical literature. Much of the data is also available to the astronomical community on the web at http://www.astrochemistry.org/pahdata/index.html.

Today, scientists around the world are incorporating these data into comprehensive new astrophysical models — models far more sophisticated and physically realistic than the crude illustrative example above. Those models use the measured absorption data to calculate PAH *emission* spectra as a function of such astrophysical parameters as radiation field intensity, charge balance, extinction, and density. Models such as this hold the key to unlocking the potential of PAHs as probes of the interstellar medium, and it is the through the availability of this database that that goal will be realized. ❑

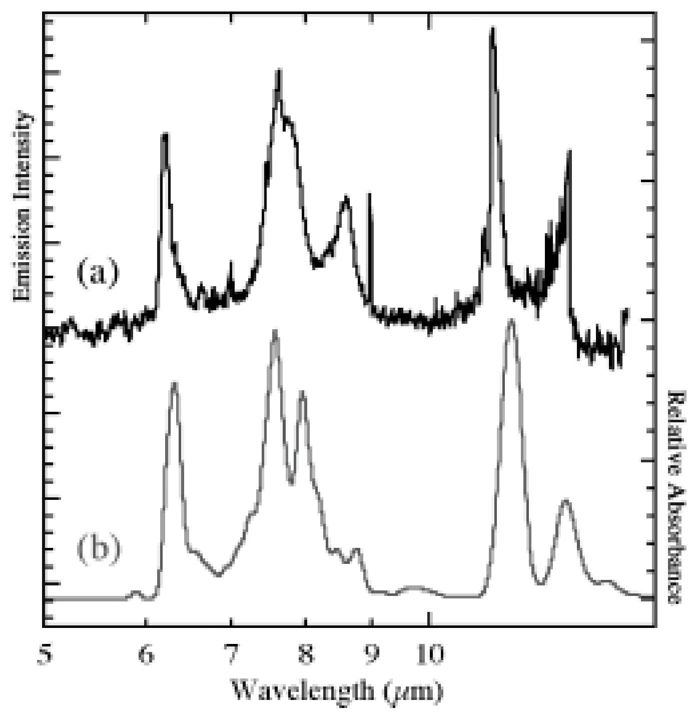

Figure 3: Comparison of a typical ISM infrared emission spectrum with the composite absorption spectrum generated by coadding the individual spectra of 11 PAHs. Figure adapted from Peeters et al., Astron.Astrophys., (2002, in press).

THE SOFIA WATER VAPOR MONITOR NEARS COMPLETION

Thomas L. Roellig, Robert Cooper, Brian Shiroyama, Regina Flores, Lunming Yuen, and Allan Meyer

The Stratospheric Observatory for Infrared Astronomy (SOFIA), a 3-meter class telescope mounted in a Boeing 747 aircraft, is being developed for NASA by a consortium consisting of the University Space Research Association, Raytheon E-Systems, and United Airlines. This new facility will be a replacement for the retired Kuiper Airborne Observatory that used to fly out of Moffett Field. As part of this development, NASA Ames Research Center is providing an instrument that will measure the integrated amount of water vapor seen along the telescope line-of-sight. Since the presence of water vapor strongly affects the astronomical infrared signals detected, such a water vapor monitor (WVM) is critical for proper calibration of the observed emission. The design and engineering model development of the water vapor monitor is now complete and the hardware to be used in the flight unit has been fabricated and is now being tested. Since the SOFIA observatory will be certified under Federal Aeronautics Administration (FAA) Part 25, extensive analysis and testing is needed, much more extensive than was required for earlier Ames airborne observatories that flew under an FAA research aircraft certification.

The SOFIA water vapor monitor measures the water vapor content of the atmosphere integrated along the line-of-sight at a 40° elevation angle by making radiometric measurements of the center and wings of the 183.3 GHz rotational line of water. These measurements are then converted to the integrated water vapor along the telescope line-of-sight. The monitor hardware consists of three physically distinct sub-systems:

1) The Radiometer Head Assembly, which contains an antenna that views the sky, a calibrated reference target, a radio-frequency (RF) switch, a mixer, a local oscillator, and an intermediate-frequency (IF) amplifier. All of these components are mounted together and are attached to the inner surface of the aircraft fuselage, so that the antenna can observe the sky through a microwave-transparent window. The radiometer and antenna were ordered from a commercial vendor and have been rebuilt and modified at Ames to include an internal reference calibrator and to meet FAA Part 25 requirements.

2) The IF Converter Box Assembly, which consist of IF filters, IF power splitters, RF amplifiers, RF power meters, analog amplifiers, A/D converters, and an RS-232 serial interface driver. These electronics are mounted in a cabinet just under the radiometer head and are connected to both the radiometer head and a dedicated WVM computer (CPU). All of the flight electronics boards have been fabricated and have been shown through testing to meet their requirements. A small micro-processor that handles the lowest level data collection and timing has been programmed in assembly language to collect and co-add the radiometer data and communicate with the software residing in the WVM CPU.

3) A dedicated WVM CPU that converts the radiometer measurements to measured microns of precipitable water and communicates with the rest of the SOFIA Mission and Communications Control System (MCCS). A non-flight version of this computer hardware has been procured for laboratory testing and the flight software is finishing its development, with approximately 95% of the software coded and unit-tested. Proper command and data communications between the Water Vapor Monitor and the SOFIA MCCS have been demonstrated using an MCCS simulator that has been developed by the SOFIA development team. ❑

USING DEUTERIUM TO TRACE THE LINKS BETWEEN INTERSTELLAR CHEMISTRY AND THE ORGANICS THAT SEEDED THE EARLY EARTH

Scott A. Sandford, Louis J. Allamandola, Max P. Bernstein, and Jason P. Dworkin

The objective of this research is to investigate the importance of interstellar chemistry in the origin and early evolution of life. The interstellar medium (ISM) mediates gas phase, gas-grain, and solid state chemical processing that produce a variety of new molecules. Since new stellar and planetary systems are produced in dense molecular clouds in the ISM, these molecules may have become incorporated into, and aided in the formation of, the early biosphere on Earth. Many of these organic compounds are relatively complex and of potential prebiotic importance. For example, we have shown that the UV irradiation of ices condensed onto grains in dense molecular clouds should produce quinones, amphiphiles, and amino acids—all compounds crucial for life.

These important compounds are irrelevant to the origin of life if they cannot survive the transition from the general dense cloud through the stellar / planet formation stage to subsequent infall onto a planetary surface. The best evidence that interstellar organics survive this process is the presence of complex organics enriched in deuterium (D) in primitive meteorites. The presence of excess D is generally taken to indicate an interstellar chemical heritage, since it has long been known that interstellar gas phase ion-molecule chemistry produces D-enriched products. In the past year we have examined the various chemical processes which can make or alter organics in the ISM (Figure 4). All of these processes should yield products enriched in D, with each process producing a unique “signature” with regards to the extent and molecular distribution of the excess D.

This work strengthens the interpretation that D enrichments in meteorites indicate the presence of organic species made in the ISM and provides a fundamental framework for the investigation of the nature of the links between interstellar chemistry, the organics in meteorites, and the origin of life on Earth, and by extension, planets in other stellar systems. ❑

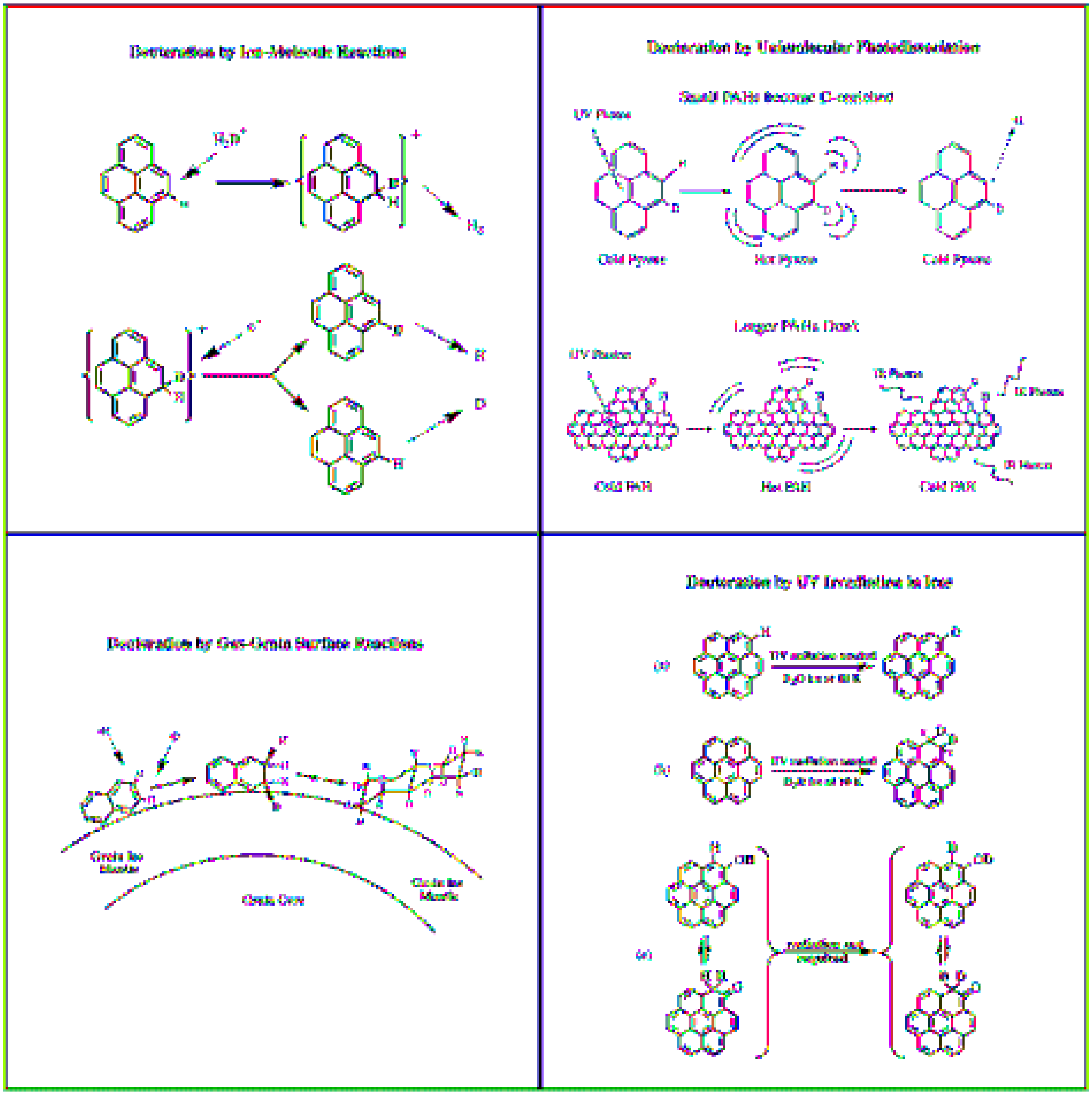

***Figure 4:* Examples of how interstellar processing by ion-molecule reactions, gas-grain surface reactions, unimolecular photodissociation, and solid state ice irradiation can result in D enrichment of the products. Each process leaves a unique signature in the placement of excess D. Polycyclic aromatic hydrocarbons (PAHs) are used to illustrate each process.**